

DEVELOPMENT OF A ULTRA SAFE, ULTRA LOW EMISSIONS ALTERNATIVE FUEL SCHOOL BUS

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This paper summarizes work done on development of an Ultra Safe, Ultra Low Emission Alternative-Fueled School Bus. This project is sponsored by the National Renewable Energy Laboratory and funded by the U.S. Department of Energy. Southwest Research Institute (SwRI) is the prime subcontractor, and the project team consists of SwRI and three subcontractors: Blue Bird, Inc., suppliers of the prototype bus, Deere Power Systems Group, the engine manufacturer, and CNG Cylinder Company, supplier of the fuel storage system. The goal of the project is to design, develop, and build a state of the art alternative-fueled school bus, with enhanced safety features, low emissions, good fuel economy, and favorable driveability. A prototype test vehicle that incorporates all of the newly developed systems has been built. Following integration of the engine and emissions control systems into the vehicle, a 10,000 mile demonstration test will be conducted. This testing will help to evaluate driveability and reliability of the engine and bus systems.

The project has made considerable progress in the last year. A prototype school bus was designed and constructed. This bus incorporated many new technologies to increase the safety of the bus passengers as well as pedestrians boarding and leaving the bus. These technologies emphasized increased visibility between the bus driver and pedestrians or vehicles, and included the use of high intensity discharge lighting, pedestrian and vehicle detection systems, and remote-mounted cameras. Passenger safety was also stressed, with the application of seat belts and improved emergency exits and lighting. An advanced, safe fuel storage system was also developed. In addition, a natural gas-fueled engine was developed for powering the bus. The development process focused primarily on improvements to the lean operation of the engine and control system advancements. The control system development included investigations into alternative control algorithms for steady-state and transient operation, various fuel metering devices, as well as new methods for wastegate control, knock and misfire detection, and catalyst monitoring. Both the vehicle and engine systems represent state-of-the-art technologies. Integration of the vehicle and engine is planned for the next phase of the project, followed by a demonstration test of the overall vehicle system.

Vehicle Development

The prototype bus is a departure from conventional bus designs. A photograph of the new bus is shown in Figure 1. The bus chassis and body are totally new designs, and the designs embody many ideas and technologies not currently used in production school buses.

A major theme in the design of this vehicle was to increase the visibility of pedestrians to the driver, as well as increase the visibility of the bus itself. To accommodate this, the front portion of the body was redesigned to lower the windshield for improved visibility. To further increase visibility, a Data Vision head up display (HUD) system was incorporated. This system projects pertinent information onto the windshield so that drivers do not have to divert their eyes from the road. Both video and instrumentation information can be displayed. Cameras located at strategic points allow the driver to watch views of the side and rear of the bus on the HUD. The HUD will also display several parameters from the bus instrumentation, such as vehicle

speed and warning indicators. Several holographic technologies are employed to increase visibility. A holographic lookdown strip on the windshield will increase the driver's viewing area by allowing him/her to view a portion of the space below the windshield that is normally in his/her blind spot. Also, a holographic "STOP" sign is mounted to the right front windshield and the rear window. This sign will flash the word "STOP" when the warning lamps are on to provide greater visibility of the vehicle when stopped. The photograph of the front of the bus in Figure 2 clearly shows this sign, as well as some of the other lighting systems. High intensity discharge Lighting (HID) was used in the bus, since it provides a greatly expanded light pattern, increased service life, and more light output with a 20% reduction in power requirements. The HID includes low beam headlamps, entry door lighting, side pedestrian safety lighting, rear wheel safety lighting, and emergency door lighting. In addition, fiber optic emergency aisle lighting is used to illuminate the aisle during emergencies. The red and amber warning lamps located at the top of the bus are strobe lights which provide greater visibility of the vehicle. Also, the bus is equipped with daytime running lights (DRL), which provide greater visibility to other drivers and reduce the potential for accidents. These DRL are effective in preventing collisions involving a vehicle pulling out in front of another vehicle, lane changing collisions, and head-on collisions.

Pedestrian/vehicle safety is provided with an automotive radar system which detects and informs the driver of other vehicles traveling in the blind spot region of the vehicle. Also, the Forewarn system, a type of proximity sensor, is used in the vehicle blind spots. This system alerts the driver of children moving within its detection areas. One sensor monitors the area around the stepwell and the front of the bus. A second sensor located on the curbside monitors the area around the rear axle. The system is active while the bus is stopped and the door is open. If a pedestrian moves into one of the detection zones, a warning alarm sounds and a visual indicator is illuminated on the Forewarn system screen.

The passenger seats are high-back school bus seats which meet FMVSS 222. The seats include 3 emergency locking lap and shoulder belts integrated into the seat padding. Also, two of the seats have integrated child safety seats for small children. The bus also has many emergency exits. These include two push-out windows on each side, two roof hatches, and a side emergency door. In addition, a large emergency exit window is provided in the rear center of the vehicle. The vehicle back-up lamps are also activated upon opening of this window exit to provide area lighting.

Fire and explosion protection is provided through a fire and gas detection system that uses signals from sensors strategically located in the bus and engine compartment. The driver is alerted immediately by visual and audible alarms if an overheat condition occurs and/or the air is contaminated with natural gas. The fire suppression system can detect and extinguish a fire in its earliest stages.

Additional vehicle systems include a Global Positioning System (GPS) for monitoring the location of the bus and providing route information, a Learning Center, equipped with a VCR, monitors and speakers to provide additional educational opportunities, and a cellular phone, so that emergency calls can be made.

The design of the chassis is also completely novel. The frame rails were designed so that the CNG fuel tanks were mounted completely between the frame rails of the chassis, and removal and installation of the tanks would be easily. A new four wheel, anti-lock disc brake system that provided superior braking performance was also incorporated.

The fuel storage system consists of four 15 inch diameter, 84 inch long cylinders manufactured by CNG Cylinder Company. These tanks have a total capacity of 6872 SCF at 3000 psi. The CNG fuel system complies to NFPA 52 and FMVSS 303, Fuel System Integrity for Compressed Natural Gas Vehicles. The storage cylinders comply to NHTSA FMVSS 304 and NGV2-2 specifications. Fiberglass-wrapped aluminum cylinders were used since they were a proven design offering the maximum storage volume available.

Engine Development

The base engine used in the project is the John Deere PowerTech 8.1L engine. This engine was originally developed at SwRI for John Deere to be a state of the art electronically-controlled engine. The

PowerTech 8.1L engine has electronic fuel injection, an electronic drive-by-wire throttle actuator, an electronically controlled wastegate, and a direct fire, coil-on-plug ignition system. For this project, the production control system was replaced with the SwRI-developed Rapid Prototyping Engine Control System (RPECS), a PC-based flexible full authority engine controller. A photograph of the engine and controller used on this project is shown in Figure 3. The RPECS facilitated the investigation of the new control system technologies; in particular, the system was used to evaluate new control algorithms, sensors and other control hardware. The engine development portion of the project concentrated on three tasks: engine optimization, advanced control technologies, and onboard diagnostics capabilities.

Engine optimization work focused on improving the lean performance of the engine. An investigation into the causes of lean misfire was conducted, to determine what factors had the largest influence on the lean performance of the engine. This investigation revealed that the lean misfire limit of the engine could be improved through modifications which reduced the residual gas fraction in the combustion chamber. High humidity was also found to be quite detrimental in the ability of the engine to run very lean. These results lead to a redesign of the exhaust system, a rematch of the turbocharger, and combustion chamber modifications. The emissions calibration was modified based on extensive engine mapping. The improvements made to the engine are summarized in Figure 4. This plot shows thermal efficiency and unburned hydrocarbon (HC) emissions at equivalent levels of NO_x and combustion stability. Note the significant increase in thermal efficiency and decrease in HC emissions.

A great deal of work was devoted to an investigation of the advanced control technologies. In particular, an in-depth study of various air-fuel ratio control algorithms was conducted. This study produced a very successful observer-based algorithm, which eliminated the need for exhaust pressure sensors, and provided extremely good air-fuel ratio control. Alternative fuel metering methods were also tested, to determine if any advantage could be obtained compared to the production fuel injectors. The test results indicated that using fuel injectors was the best fuel metering method, but several proportional flow valves also showed satisfactory performance. Control technology for the turbocharger, including reduction of throttling losses, elimination of surge, and improved transient compensation to improve the driveability of the engine was also developed. Also, based on the results of the lean misfire investigation conducted during the engine optimization task, a practical humidity sensing and compensation system was developed and proven on the engine.

Several onboard diagnostic methods were developed specifically for this project. A knock detection and control system, based on a SwRI-designed magnetostrictive knock sensor, was successfully developed. Figure 5 is a plot of the knock control system in action during a rapid change in engine load from minimum load to maximum load at a constant speed of 2000 rpm. Note that as the knock sensor detects knocking, the spark timing is retarded incrementally with each occurrence to reduce knocking. Other onboard diagnostic technologies investigated were misfire detection and control, and catalyst monitoring. A misfire detection system based on instantaneous crank angle velocity (ICAV) measurements was found to be the most practical. No practical system for catalyst monitoring was developed during this project, but several methods, including a dual UEGO sensor system, CO sensors, and a catalytic sensor were tested.

The mechanical modifications to the engine have been completed. Several of the new control and diagnostic technologies are to be incorporated into the bus by the end of 1996. An auxiliary control module which handles the additional control tasks has been developed. Software development for the production controller is planned for the next two months.